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Outcome similarity modulates retroactive interference between cues trained apart

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Retroactive interference between cues trained apart has been regarded as an effect that occurs because the target and interfering associations share a common outcome. Although this view is consistent with evidence in the verbal learning tradition (Underwood, 1966) and, more recently, in predictive learning with humans (Pineño & Matute, 2000), little research has been conducted to ascertain whether the occurrence of this effect critically depends on the target and interfering associations sharing an identical outcome. The present experiment examined, in predictive learning with humans, retroactive interference between cues trained apart as a function of the similarity of the outcome paired with the cues. Interference was found to be stronger when the cues were paired with the same outcome than when they were paired with either similar or different outcomes.

Since Kamin's (1968) original study on forward blocking it is well known in the associative learning literature that responding to a target cue, X, does not only depend on the number of pairings of this cue with the outcome, but also on the number of pairings of the outcome with an alternative cue, A, that has been presented in compound with X during training. The same is true for the effect known as backward blocking (Shanks, 1985; Miller & Matute, 1996), in which the AX compound is paired with the outcome prior to training with A. Forward and backward blocking, among other effects (e.g., overshadowing and relative validity), represent what is generally referred to as *cue competition effects*, namely, that cues trained in compound with the same

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outcome compete for behavioral control. Cue competition effects have been largely studied with both human and nonhuman animals and have encouraged the development of a great variety of associative models of learning (e.g., Dickinson & Burke, 1996; Mackintosh, 1975; Miller & Matzel, 1988; Pearce & Hall, 1980; Rescorla & Wagner, 1972; Van Hamme & Wasserman, 1994; Wagner, 1981). Despite several differences, most models of learning assume that, in order for cues to compete, they must be trained in compound (i.e., together) with the same outcome.

A few years ago, however, Matute and Pineño (1998b) observed that cues can also compete even if they are never trained together. Their experiments showed that responding to a cue, X, paired with the outcome (i.e., X-O) in an early stage of the experiment can be attenuated due to the subsequent training of another cue, A, with the same outcome (i.e., A-O). In other words, training of A with the outcome retroactively interfered with the expression of the previously learned X-O association. Matute and Pineño's demonstration of retroactive interference between cues trained apart was not novel, but it can be regarded as an application to predictive learning of the well-known interference effects observed in the verbal learning tradition (e.g., Underwood, 1966). Specifically, the effect of retroactive interference between cues trained apart can be regarded as analogous to the A-B, C-B paradigm in the paired associates literature (e.g., Abra, 1967; Cheung & Goulet, 1968; Johnston, 1968; Keppel, Bonge, Strand, & Parker, 1971; Schwartz, 1968).

Although extensive research has been conducted on the effect of retroactive interference between cues trained apart (e.g., Escobar, Arcediano, & Miller, 2001; Escobar, Matute, & Miller, 2001; Escobar, Pineño, & Matute, 2002; Lipp & Dal Santo, 2002; Matute & Pineño, 1998b; Pineño, Ortega, & Matute, 2000; Pineño & Matute, 2000), the most basic question remains to be answered yet: Why does training of the A-O association interfere with the expression of the X-O association? Several experiments have demonstrated that this effect occurs only when the target and interfering associations share a common outcome (e.g., Escobar, Arcediano, & Miller, 2001; Pineño & Matute, 2000). Thus, the effect of retroactive interference between cues trained apart has been regarded as symmetrical to those effects of retroactive interference between outcomes trained apart (e.g., extinction and counterconditioning), in which the target and interfering associations share the cue as the common element (see Pineño & Matute, 2000). Moreover, the observation that both of these effects, retroactive interference between cues trained apart and retroactive interference between outcomes trained apart, are determined by the target and interfering associations sharing a common element led to the proposal that these effects could be caused by a common mechanism (Matute & Pineño, 1998a). As proposed by Pineño and Matute (1998b) and Miller and Escobar (2002), retroactive interference between cues trained apart could be explained by a priming process akin to the one of Bouton's (1993) theory, which was developed to explain interference between outcomes trained apart. In this framework, when the target and interfering associations share a common element (i.e., the outcome in retroactive interference between cues trained apart and the cue in retroactive interference between outcomes trained apart) and the interfering association is better primed for retrieval than the target association (i.e., due to contextual and/or punctuate cues or by the recency of its training), retrieval of the target association is impaired. This impaired retrieval of the target association can be viewed as akin to what in the memory literature is generally referred to as retrieval inhibition (see Bjork, 1989) or retrieval-induced forgetting (see Anderson, Bjork, & Bjork, 2000).

Due to the critical role attributed to the common element shared by the target and interfering associations in the observation of interference, studying its actual contribution to interference is of critical importance. One approach that has been used to assess the role of the common element on proactive interference consists of varying its similarity in the target and interfering association. For example, some classic studies have shown that similarity between the to-be-recalled and interfering items strongly determines proactive interference in short-term memory (e.g., Delaney & Logan, 1979; Wickens, Born, & Allen, 1963). To our knowledge, however, there are no studies showing that the same is true for retroactive interference. Moreover, in the predictive learning paradigm, the influence of the similarity between the common elements has received little empirical attention. The only exception to this was provided by Escobar and Miller (2003, Experiment 3), who showed that retroactive interference between cues trained apart is stronger as the temporal duration of the outcomes trained with the target and interfering cues is more similar. Therefore, other manipulations of similarity, such as manipulating the *physical* similarity of the outcomes, are critical to assess the actual role played by the outcome in the occurrence of retroactive interference between cues trained apart. This was the purpose of the present study.

EXPERIMENT

In this experiment, three groups of participants were first given pairings of the target cue, X, and an appetitive outcome (i.e., $O1_{Ap}$). The critical treatment was given in Phase 2. In this phase, group IO (i.e., identical outcome) received pairings of cue A with the same outcome that was previously paired with X (i.e., A-$O1_{Ap}$ trials). Group SO (i.e., similar outcome) received pairings of A with an appetitive outcome that was slightly different from the outcome previously paired with X (i.e., A-$O2_{Ap}$ trials). Finally, group DO (i.e., different outcome) was given presentations of A followed by a completely different outcome, specifically, a neutral outcome that did not elicit responding (i.e., A-O_{Ne} trials).

If retroactive interference between cues trained apart is determined by the target and interfering associations sharing an identical outcome, then interference should only occur in group IO (i.e., as showed by weak responding to X at test in comparison to group DO). Moreover, if outcome similarity modulates retroactive interference between cues trained apart, then a certain degree of interference should also be observed in group SO as compared to group DO.

METHOD

Participants and Apparatus. The participants were one hundred and fifty students from Deusto University, who volunteered for the study. Participants were randomly assigned to groups IO (n = 54), SO (n = 51), and DO (n = 45). The experiment was run in three replications, with the participants being similarly distributed across groups in each replication. The computers were located in a large room that allowed for simultaneous running of about 70 participants. Participants were seated about 1.5 m apart, and each subject was exposed to a different experimental condition (and counterbalancing of stimuli) than the two adjacent subjects.

Design and Procedure. Table 1 summarizes the design of the experiment. During Phase 1, all groups were given fifteen trials on which the target cue, X, was paired with one of the appetitive outcomes (i.e., X-$O1_{Ap}$ trials), interspersed with fifteen trials on which cue C was paired with an aversive outcome (i.e., C-O_{Av} trials). Presentations of C-O_{Av} were filler trials that were included in order to prevent cue generalization that would result in strong responding appropriate to $O1_{Ap}$ to all cues. In Phase 2, all groups were given fifteen trials with a third cue, A. In group IO, cue A was paired with the same outcome previously paired with cue X during Phase 1 (i.e., $O1_{Ap}$). In group SO, cue A was paired with the alternative appetitive outcome (i.e., $O2_{Ap}$). In group DO, cue A was paired with a neutral outcome during Phase 2 (i.e., O_{Ne}). At test, all groups were given a single presentation of cue X.

The preparation used in this experiment was the same as that previously used by Pineño et al. (2000) for the study of associative learning with humans. In this preparation, participants were instructed to imagine that they were to rescue a group of refugees by helping them escape from a war zone in trucks (see Pineño et al.; Pineño & Matute, 2000; for a detailed description of the task, including the instructions[1]).

The cues were presented on a so-called spy-radio, which consisted of six panels in which colored lights could be presented. Cues X, A and C were blue, red, and yellow lights, counterbalanced. In this experiment, on each trial a randomly chosen light position in the array was illuminated with the color of that trial's cue. Cue durations were 3 s. On each trial, the termination of the cue coincided with the presentation of an outcome. The appetitive outcomes (i.e., $O1_{Ap}$ and $O2_{Ap}$) consisted of (a) the messages '[*n*] refugees safe at home!!!' or '[*n*] refugees safe at the embassy!!!', counterbalanced (with [*n*] being the number of refugees placed in the truck during the cue presentation)

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[1] A demonstration version of this preparation can be downloaded from http://paginaspersonales.deusto.es/matute/software.html
(see also http://www.opineno.com/task.htm for a new adaptation of this preparation).

and, (b) gaining one point for each refugee who was safe. The aversive outcome (O_{Av}) consisted of (a) the message '[*n*] refugees have died!!!' and, (b) losing one point for each refugee who died in the truck. The neutral outcome (O_{Ne}) consisted of (a) the message 'Road closed' and, (b) no point change. Outcome messages were presented for 3 s. During the intertrial intervals, the lights were turned off (i.e., gray). The mean intertrial interval duration was 5 s, ranging between 3 and 7 s.

Table 1. Design Summary of the Experiment.

Group	Treatment		Test
	Phase 1	Phase 2	
IO	15 X-$O1_{Ap}$ / 15 C-O_{Av}	15 A-$O1_{Ap}$	1 X
SO	15 X-$O1_{Ap}$ / 15 C-O_{Av}	15 A-$O2_{Ap}$	1 X
DO	15 X-$O1_{Ap}$ / 15 C-O_{Av}	15 A-O_{Ne}	1 X

Note. A and X were the critical cues. C was included to prevent strong cue generalization. These cues were blue, red, and yellow colors, counterbalanced. Presentations of X were always followed by an appetitive outcome ($O1_{Ap}$), whereas presentations of C were always followed by the aversive outcome (O_{Av}). Presentations of A were followed by $O1_{Ap}$ in group IO, by a different appetitive outcome ($O2_{Ap}$) in group SO, and by the neutral outcome (O_{Ne}) in group DO. Trial types separated by a slash were interspersed. The numbers denote the number of presentations of each trial type in each phase.

During each cue presentation, each response (i.e., pressing the space bar once) placed one refugee in the truck, whereas holding the space bar down placed up to 30 refugees per second in the truck. The number of refugees that participants loaded in the truck on each trial (i.e., regardless of the number of space bar presses) was our dependent variable, which can be viewed as reflecting the participants' expectation of the cue being followed by an appetitive outcome ($O1_{Ap}$ or $O2_{Ap}$). Presumably, the more certain the participants were that the cue would be followed by an appetitive outcome, the greater number of refugees they would load in the truck, whereas the more certain participants were that the truck would explode (O_{Av}) or that the road would be closed (O_{Ne}), the fewer refugees they would place in the truck. The number of refugees that participants loaded in the truck during each cue presentation was shown in a box on the screen, this number being immediately updated after each response. Although pressing the space bar during the outcome message had no consequences, the number of refugees loaded in the truck during the previous cue presentation remained visible during the presentation of the outcome. Upon outcome termination, the score panel was initialized to 0. Responses that occurred during the intertrial intervals had no consequence and were not reflected in the panel. The different phases of the experiment were conducted without interruption.

Preanalysis Treatment of the Data. Prior to any analyses, as in our previous studies using this task (e.g., Pineño & Matute, 2000; Pineño et al., 2000), we used a data selection criterion in order to ensure that participants were attending to the experiment and had learned to discriminate between cues that signaled either the appetitive or the aversive outcome during Phase 1 (i.e., X and C, respectively). According to this criterion, the number of responses given to cue X during the last trial in which it was presented during Phase 1 had to be higher than the number of responses given to cue C on its last presentation during Phase 1. Following this criterion, two participants from group SO were eliminated from the experiment.

RESULTS

Preliminary Analyses

Pooling data over replications. The critical results of the experiment (i.e., the results on Test of X) did not differ among replications, as shown by a 3 (Replication) x 3 (Group) analysis of variance (ANOVA) on the mean number of responses to X at test. This ANOVA showed neither a main effect of replication, $p > .12$, nor a Replication x Group interaction, $p > .16$. Therefore, the data from the three replications were pooled in the subsequent analyses.

Training Results

The top panel of Figure 1 depicts the mean number of responses during training, averaged over blocks of five trials. As can be seen in the top-left panel of this figure, during Phase 1 responding to each of the cues, X and C, did not appreciably differ among groups. Also, during this phase responding to cue X was seemingly stronger than responding to cue C in all groups (something that is not surprising since the data selection criterion ensured that all participants discriminated between X and C in this phase). These two impressions were confirmed by a 3 (Group) x 2 (Cue) x 3 (Block of 5 Trials) ANOVA on the mean number of responses, which yielded main effects of cue, $F(1, 145) = 3750.26$, $MSE = 168.46$, $p < .001$, and block of 5 trials, $F(2, 290) = 570.34$, $MSE = 32.67$, $p < .001$. Also, this ANOVA revealed a Cue x Block of 5 Trials interaction, $F(2, 290) = 587.87$, $MSE = 39.55$, $p < .001$. Neither the main effect of group, nor any interaction involving group as a factor proved significant, $p > .15$.

The results from Phase 2 can be seen in the top-right panel of Figure 1. Responding to cue A was similar in groups IO and SO, and stronger than in group DO. This impression was confirmed by a 3 (Group) x 3 (Block of 5 Trials) ANOVA on the mean number of responses to cue A during Phase 2, which yielded main effects of group, $F(2, 145) = 473.21$, $MSE = 278.12$, $p < .001$, and of blocks of 5 trials, $F(2, 290) = 180.72$, $MSE = 46.47$, $p < .001$, as well as a Group x Blocks of 5 Trials interaction, $F(4, 290) = 21.96$, $MSE = 46.47$, $p < .001$. Pairwise comparisons were performed using the error term of the ANOVA and showed that responding to A did not differ between groups IO and SO on any block of 5 trials, all ps > .16, and that responding to A was stronger in these groups than in group DO on all blocks of 5 trials, all Fs(1, 145) ≥ 387.66, all ps < .001. This is not surprising since cue A was paired with an appetitive outcome in groups IO and SO, and with a neutral outcome in group DO. Therefore, responding to cue A was not differentially affected by its being trained with the same outcome as cue X (i.e., $O1_{Ap}$, group IO) or with a similar outcome (i.e., $O2_{Ap}$, group SO). Responding to cue A was differently affected only by its being paired with an appetitive outcome (i.e., groups IO and SO) or a neutral outcome (i.e., group DO).

Test Results

The critical results in this experiment are those of the test phase, which are depicted in the bottom panel of Figure 1. As can be seen in this panel, responding to cue X was weaker in group IO than in both groups SO and DO. Also, responding to X was apparently weaker in group SO than in group DO. These impressions were supported by a one-way analysis of variance (ANOVA) among groups, which yielded an overall effect of group, $F(2, 145) = 17.15$, $MSE = 512.58$, $p < .001$. Pairwise comparisons performed using the error term of the ANOVA showed that responding in group IO was weaker than in both groups SO, $F(1, 145) = 14.64$, $p < .001$, and DO, $F(1, 145) = 32.55$, $p < .001$. However, despite the figure suggesting that responding in group SO was weaker than in group DO, pairwise comparisons showed that this difference was only marginally significant, $F(1, 145) = 3.69$, $p = .056$.

The mean number of responses during the 3-s period previous to the presentation of X at test was 10.37 (SEM = 4.48), 7.14 (SEM = 3.88), and 0.20 (SEM = 0.20) for groups IO, SO, DO, respectively. This stronger responding before the presentation of cue X at test in groups IO and SO than in group DO might be due to participants in groups IO and SO anticipating another reinforced presentation of cue A and participants in group DO probably expecting another nonreinforced presentation of this cue. Although a one-way ANOVA on the mean number of responses during the pre-cue period at test of X yielded no effect of group, $p > .13$, pairwise comparisons performed using the error term of the ANOVA showed that responding in the pre-cue period was stronger in group IO than in group DO, $F(1, 145) = 3.95$, $p < .05$. Despite this stronger response in group IO than in group DO being conservative (i.e., we expected these two groups to differ in the opposite direction during the cue presentation at testing), in order to minimize the potential influence of the pre-cue number of responses on the number of responses at test, we performed an additional analysis with the test results including the pre-cue scores as a covariate.

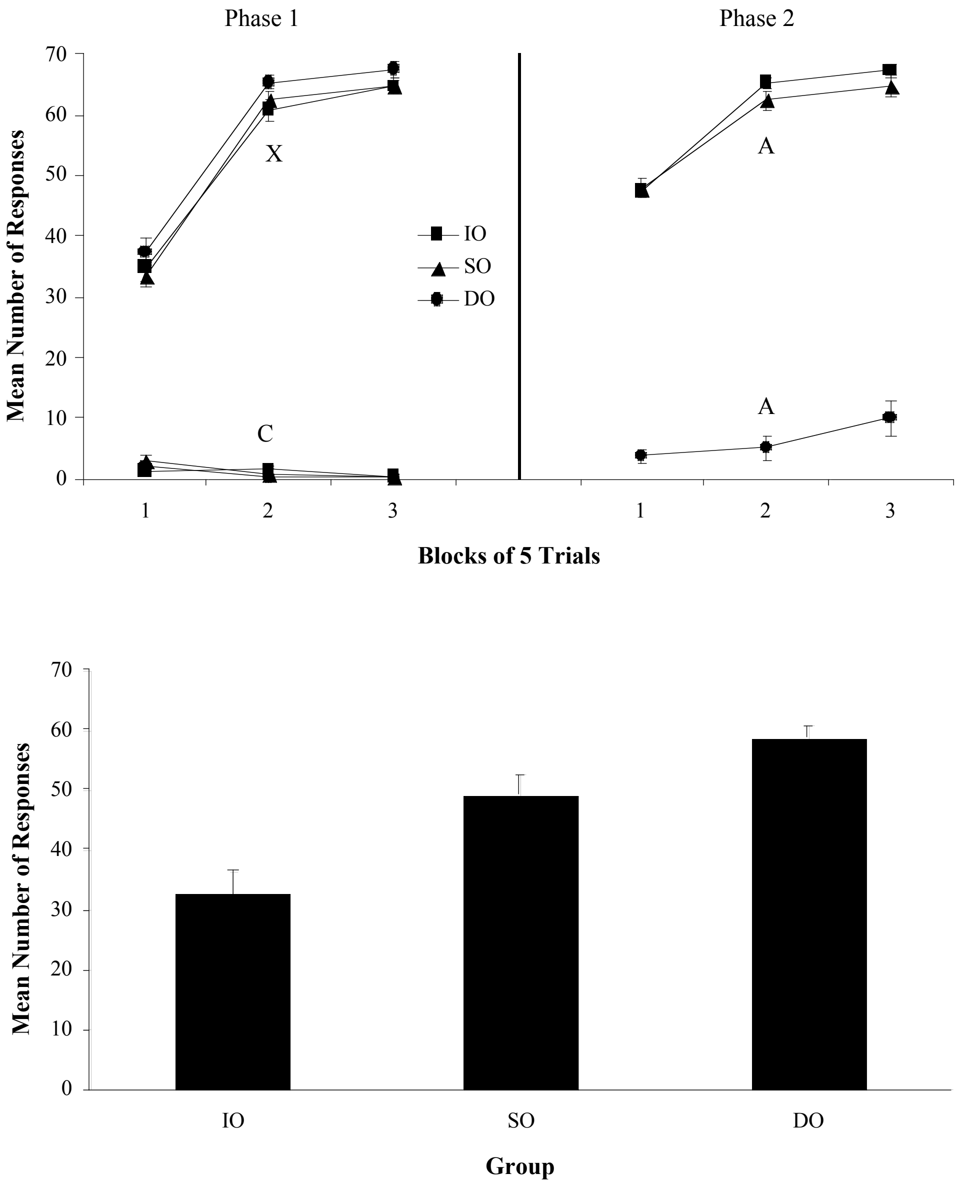

Figure 1. Top panel: Mean number of responses to cues X, A and C during training, averaged over blocks of 5 trials. Bottom panel: Mean number of responses to X at test. Error bars depict standard error of the means.

An analysis of covariance (ANCOVA) among groups including the pre-cue number of responses as a covariant revealed an overall effect of group, $F(2, 144) = 17.52$, $MSE = 513.33$, $p < .001$. The ANCOVA adjusted means for responding to X at test were 32.40, 49.71, and 59.15 in groups IO, SO, and DO, respectively. Pairwise comparisons performed using the error term of the ANCOVA confirmed the previous result, that is, that responding in group IO was weaker than in both groups SO, $F(1, 144) = 14.94$, $p < .001$, and DO, $F(1, 144) = 33.29$, $p < .001$. Also, contrary to what was observed in the previous analyses that did not include the pre-cue scores as a covariant, pairwise comparisons showed that responding was also weaker in group SO than in group DO, $F(1, 144) = 4.02$, $p < .05$.

DISCUSSION

As in previous studies (e.g., Escobar, Arcediano, & Miller, 2001; Escobar, Matute, & Miller, 2001; Escobar et al., 2002; Matute & Pineño, 1998b; Pineño et al., 2000; Pineño & Matute, 2000), the present experiment found a strong effect of retroactive interference between cues trained apart in a group in which both the target cue and the interfering cue were trained with the same outcome (i.e., group IO). Also, retroactive interference between cues trained apart was also found to occur (although weakly) in a group in which the target and interfering cues were paired with different appetitive outcomes or, in other words, with similar outcomes that were of the same valence and, hence, produced the same response (i.e., group SO). This latter result must be qualified because responding to the target cue at test was significantly weaker in group SO than in group DO *only* when the analyses included the pre-cue number of responses as a covariant (see Results section). Of critical importance, interference was weaker in group SO than in group IO, a result that was found regardless of whether the pre-cue number of responses was included as a covariant in our analyses. Therefore, these results indicate that retroactive interference between cues trained apart can take place as a function of the similarity between the outcomes associated with the target and interfering cues.

These results in the area of predictive learning are consistent with classic studies in the verbal learning tradition (e.g., Delaney & Logan, 1979; Wickens et al., 1963), which showed that proactive interference is strongly determined by the similarity of the to-be-recalled item and the interfering item (see also Osgood, 1949; Robinson, 1927). They are also consistent with the recent study of Escobar and Miller (2003), who found that temporal similarity of the outcomes trained with the target and interfering cues also modulates retroactive interference between cues trained apart. If, as proposed by Escobar and Miller, stimuli are viewed as having multiple components (e.g., physical characteristics, temporal duration, and motivational properties), the influence of outcome similarity in retroactive interference can be understood from a broader perspective. In this framework, as the representation of the outcome that is physically present during interfering training better matches the memory of the representation of the outcome previously paired with the target cue, responding to the target cue will result more strongly interfered.

RESUMEN

La semejanza de las consecuencias modula la interferencia retroactiva entre claves entrenadas separadamente. La interferencia retroactiva entre claves entrenadas separadamente ha sido considerada como un efecto que ocurre debido a que las asociaciones "diana" e interfiriente comparten una consecuencia común. Aunque este punto de vista es consistente con la evidencia en la tradición del aprendizaje verbal (Underwood, 1966) y, más recientemente, en el aprendizaje predictivo con humanos (Pineño y Matute, 2000), se ha llevado a cabo escasa investigación para averiguar si la ocurrencia de este efecto depende críticamente de que las asociaciones "diana" e interfiriente compartan una consecuencia idéntica. El presente experimento estudió, en aprendizaje predictivo con humanos, la interferencia retroactiva entre claves entrenadas separadamente en función de la semejanza de las consecuencias emparejadas con las claves. Se encontró una interferencia más fuerte cuando las claves fueron emparejadas con la misma consecuencia que cuando fueron emparejadas con consecuencias similares o diferentes.

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